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Contents

1 Strategic Plan 2012-2016

In 2012 the Institute produced a new strategic plan covering the period 2012-2016[1]. As part of the development of this overarching Institutional strategy each school also produced its own strategic programme of activities. In the case of the School of Cosmic Physics this identified four broad 'pillars' that together support the school. The first and most important of these is the School's reputation for pioneering and excellent research, the others being its contributions to the third-level educational system, its involvement in shared research infrastructure and general public service and finally its work in public outreach. This report aims as far as possible to follow this structure.

2 Research Work

2.1 Star Formation

2.1.1 Submitted Proposals

SFI: A proposal by T.P. Ray to Science Foundation Ireland (Investigator Award Programme) on the development of Kinetic Inductance Detectors (KIDS) jointly with the Cavendish Laboratory in Cambridge, the Centre for Research and Adaptive Nanostructures and Nanodevices (CRANN) and the Department of Physics, NUI Maynooth was accepted by SFI to pass to Phase II. A decision on funding (Request 1.3 Million Euro) is expected is early 2013. ERC: An ERC Advanced Grant application has been submitted (in November 2012) to investigate the link between accretion and outflow in young stars using a combination of techniques: long-term monitoring of their spectral signatures (with Liverpool John Moores University), near-infrared interferometry (with the University of Grenoble), radio interferometry and Zeeman Doppler Imaging (with the University of Göttingen).

[1] http://www.dias.ie/images/stories/admin/Strategystatements/diasstrategic%20plan2012-2016.pdf

A. Scholz (Schrödinger Fellow) is currently preparing an ERC Consolidator Grant application.

Telescope Proposals Applications involving the Star Formation Group to use ESO's Very Large Telescope (VLT) and Atacama Large Millimetre Array (ALMA) in Chile and India's Giant Meter Radio Telescope (GMRT) near Mumbai were successful in being awarded time.

2.1.2 Accretion and Disk Properties of Young Stars

A systematic survey for eruptive young stellar objects using mid-infrared photometry *A. Scholz, D. Froebrich (Kent) and K. Wood (St. Andrews)*

Accretion in young stellar objects (YSOs) is at least partially episodic, i.e. periods with high accretion rates ('bursts') are interspersed by quiescent phases. These bursts manifest themselves as eruptive variability. Scholz et al. presented a systematic survey for eruptive YSOs aiming to constrain the frequency of accretion bursts. They compared mid-infrared photometry from Spitzer and WISE separated by approximately 5 years for two samples of YSOs, in nearby star-forming regions and in the Galactic Plane, each comprising about 4000 young sources. All objects for which the brightness at 3.6 and 4.5 μm is increased by at least 1 mag between the two epochs may be eruptive variables and burst candidates. For these objects, they carried out follow-up observations in the near-infrared. They discovered two new eruptive variables in the Galactic Plane which could be FU Ori-type objects, with K-band amplitudes of more than 1.5 mag. One object known to undergo an accretion burst, V2492 Cyg, is recovered by their search as well. In addition, the young star ISO-Oph-50, previously suspected to be an eruptive object, was found to be better explained by a disc with varying circumstellar obscuration. In total, the number of burst events in a sample of 4000 YSOs is 1-4. Assuming that all YSOs undergo episodic accretion, this constraint can be used to show that phases of strong accretion ($>10^{-6}$ M_{sun} yr^{-1}) occur in intervals of

about 10^4 years, most likely between 5,000 and 50,000 years. This is consistent with the dynamical time-scales for outflows, but not with the separations of emission knots in outflows, indicating that episodic accretion could either trigger or stop collimated large-scale outflows. These results will be published in Monthly Notices of the Royal Astronomical Society.

The frequency of large variations in the near-infrared fluxes of T Tauri stars *A. Scholz*

Variability is a characteristic feature of young stellar objects (YSOs) and could contribute to the large scatter observed in Hertzsprung-Russell (HR) diagrams for star-forming regions. For typical YSOs, however, the long-term effects of variability are poorly constrained. A. Scholz has used archived near-infrared photometry from the 2 Micron All Sky Survey (2MASS), UKIDSS and DENIS to investigate the long-term variability of high-confidence members of the four star-forming regions ρ-Oph, ONC, IC348 and NGC 1333. The total sample comprises more than 600 objects, from which approximately 320 are considered to have a disc. The data set covers time-scales up to 8 yr. About half of the YSOs are variable on a 2σ level, with median amplitudes of 5-20%. The fraction of highly variable objects with amplitudes > 0.5 mag in at least two near-infrared bands is very low: 2% for the entire sample and 3% for objects with discs. These sources with strong variability are mostly objects with discs and are prime targets for follow-up studies. A transition disc candidate in IC348 is found to have strong K-band variations, likely originating in the disc. The variability amplitudes are largest in NGC 1333, presumably because it is the youngest sample of YSOs. The frequency of highly variable objects also increases with the time window of the observations (from weeks to years). These results have three implications. (1) When deriving luminosities for YSOs from near-infrared magnitudes, the typical error introduced by variability is in the range of 5-20% and depends on disc fraction and possibly age. (2) Variability is a negligible contribution to the scatter in HR diagrams of star-forming regions (except for a small number of extreme objects), if luminosities are derived from near-infrared magnitudes. (3) Accretion outbursts with an increase in mass accretion rate by several orders of magnitudes, as required in scenarios for episodic accretion, occur with a duty cycle of > 2000-2500 years in the Class II phase. The results have been published in Monthly Notices of the Royal Astronomical Society.

LAMP: the long-term accretion monitoring programme of T Tauri stars in Chamaeleon I *G. Costigan, A. Scholz, B. Stelzer (Palmero), T.P. Ray, J. Vink (Armagh), S. Mohanty (Imperial College London)*

G. Costigan (DIAS PhD student) et al. have presented the results of a variability study of accreting young stellar objects in the Chameleon I star-forming region, based on approximately 300Å high-resolution optical spectra from the Fibre Large Area Multi-Element Spectrograph (FLAMES) at the Europeantheir Southern Observatory (ESO) Very Large Telescope (VLT). 25 objects with spectral types from G2-M5.75 were observed 12 times over the course of 15 months. Using the emission lines Hα (6562.81Å) and Ca II (8662.1Å) as accretion indicators, they found 10 accreting and 15 non-accreting objects. They derived accretion rates for all accretors in the sample using the Hα equivalent width, Hα 10 per cent width and Ca II (8662.1 Å) equivalent width. They found that the Hα equivalent widths of accretors varied by $\approx$ 7-100 Å over the 15-month period. This corresponds to a mean amplitude of variations in the derived accretion rate of $\approx$ 0.37 dex. The amplitudes of variations in the derived accretion rate from Ca II equivalent width were $\approx$ 0.83 dex and those from Hα 10 per cent width were $\approx$ 1.11 dex. Based on the large amplitudes of variations in accretion rate derived from the Hα 10 per cent width with respect to the other diagnostics, they do not consider it to be a reliable accretion rate estimator. Assuming the variations in Hα and Ca II equivalent width accretion rates to be closer to the true value, these suggest that the spread that was found around the accretion rate to stellar-mass relation is not due to the variability of individual objects on time-scales of weeks to around 1 year. From these variations,

they can also infer that the accretion rates are stable within <0.37 dex over time-scales of less than 15 months. A major portion of the accretion variability was found to occur over periods shorter than the shortest time-scales in their observations, 8-25 days, which are comparable with the rotation periods of these young stellar objects. This could be an indication that what they are probing is spatial structure in the accretion flows and it also suggests that observations on time-scales of around a couple of weeks are sufficient to limit the total extent of accretion-rate variations in typical young stars. No episodic accretion was observed: all 10 accretors accreted continuously for the entire period of observations and, though they may have undetected low accretion rates, the non-accretors never showed any large changes in their emission that would imply a jump in accretion rate. The results were published in Monthly Notices of the Royal Astronomical Society.

POISSON project: A multi-wavelength spectroscopic and photometric survey of young protostars in L 1641 *A. Caratti o Garatti, R. Garcia Lopez (Bonn), S. Antoniucci (Florence). B. Nisini (Rome), T. Giannini (Rome), J. Eislöffel (Tautenburg), T.P. Ray, D. Lorenzetti (Rome), S. Cabrit (Paris)*

Characterising stellar and circumstellar properties of embedded young stellar objects (YSOs) is mandatory for understanding the early stages of stellar evolution. This task requires the combination of both spectroscopy and photometry, covering the widest possible wavelength range, to disentangle the various protostellar components and activities. As part of the POISSON project (Protostellar Optical-Infrared Spectral Survey On NTT), A. Caratti o Garatti, T.P. Ray et al. have presented a multi-wavelength spectroscopic and photometric investigation of embedded YSOs in L1641, with the aim of deriving their stellar parameters and evolutionary stages and to infer their accretion properties. This multi-wavelength database included low-resolution optical-IR spectra from the NTT and Spitzer (0.6-40 μm) and photometric data covering a spectral range from 0.4 to 1100 μm, which allowed them to construct the YSOs spectral energy distributions (SEDs) and to infer the main stellar parameters. The NTT optical-NIR spectra are rich in emission lines, which are mostly associated with YSO accretion, ejection, and chromospheric activities. A few emission lines, prominent ice (H_2O and CO_2), and amorphous silicate absorption features have also been detected in the Spitzer spectra. The SED analysis allowed them to group their 27 YSOs into nine Class I, eleven Flat, and seven Class II objects. However, on the basis of the derived stellar properties, only six Class I YSOs have an age of approximately 10^5 years while the others are older (5×10^5-10^6 years), and, among the Flat sources, three out of eleven are more evolved objects (5×10^6-10^7 years), indicating that geometrical effects can significantly modify the SED shapes. Inferred mass accretion rates show a wide range of values (3.6×10^{-9} to 1.2×10^{-5} $M_{sun}\,yr^{-1}$), which reflects the age spread observed in their sample well. Average values of mass accretion rates, extinction, and spectral indices decrease with the YSO class. The youngest YSOs have the highest accretion rates, whereas the oldest YSOs do not show any detectable jet activity in either images and spectra. Apart from two objects, none of the YSOs are accretion-dominated. They also observe a clear correlation among the YSO accretion rates, M_{star}, and age. For YSOs with t > 10^5 yr and 0.4 $M_{sun} \leq M_{star} \leq 1.2\ M_{sun}$, a relationship between $\dot{M}_{acc}$ and t ($\dot{M}_{acc} \propto t^{-1.2}$) has been inferred, consistent with mass accretion evolution in viscous disc models and indicating that the mass accretion decay is slower than previously assumed. Finally, their results suggest that episodic outbursts are required for Class I YSOs to reach typical classical T Tauri stars stellar masses. These results have been published in Astronomy and Astrophysics.

Radio continuum observations of Class I protostellar discs in Taurus: constraining the grey-body tail at centimetre wavelengths *A. Scaife, J. Buckle (Cambridge), R. Ainsworth (DIAS PhD student), T.P. Ray and the AMI Consortium*

A. Scaife, R. Ainsworth, T.P. Ray et al. have presented deep 1.8 cm (16 GHz) AMI radio contin-

uum imaging of seven young stellar objects in the Taurus molecular cloud. These objects have previously been extensively studied in the submm to near-infrared range and their spectral energy distributions modelled to provide reliable physical and geometrical parameters. These new data were used to constrain the properties of the long-wavelength tail of the greybody spectrum, which is expected to be dominated by emission from large dust grains in the protostellar disc. They find spectra consistent with the opacity indices expected for such a population, with an average opacity index of $\beta = 0.26 \pm 0.22$ indicating grain growth within the discs. They used spectra fitted jointly to radio and submm data to separate the contributions from thermal dust and radio emission at 1.8 cm and derive disc masses directly from the cm-wave dust contribution. They find that disc masses derived from these flux densities under assumptions consistent with the literature are systematically higher than those calculated from submm data, and meet the criteria for giant planet formation in a number of cases. These results have been published in Monthly Notices of the Royal Astronomical Society.

2.1.3 The Formation of Brown Dwarfs and Planemos

New brown dwarf discs in Upper Scorpius observed with WISE *P. Dawson, A. Scholz, T.P. Ray, K.A. Marsh (Cardiff), K. Wood (St. Andrews), A. Natta, D. Padgett (NASA Goddard), M.E. Ressler (JPL)*

Dawson (DIAS PhD student) et al. presented a census of the disc population for United Kingdom Infrared Digital Sky Survey (UKIDSS) selected brown dwarfs in the 5-10 Myr old Upper Scorpius OB association. For 116 objects originally identified in UKIDSS, the majority of them not studied in previous publications, they obtained photometry from the Wide-Field Infrared Survey Explorer (WISE) data base. The resulting colour-magnitude and colour-colour plots clearly show two separate populations of objects, interpreted as brown dwarfs with discs (class II) and without discs (class III). They identified 27 class II brown dwarfs, 14 of them not previously known. This disc fraction (27 out of 116, or 23%) among brown dwarfs was found to be similar to results for K/M stars in Upper Scorpius, suggesting *the important result that the lifetimes of discs are independent of the mass of the central object* for low-mass stars and brown dwarfs. 5 out of 27 discs (19%) lacked excess at 3.4 and 4.6 μm and are potential transition discs (i.e. are in transition from class II to class III). The transition disc fraction is comparable to low-mass stars. They estimated that the time-scale for a typical transition from class II to class III is less than 0.4 Myr for brown dwarfs. These results suggest that the evolution of brown dwarf discs mirrors the behaviour of discs around low-mass stars, with disc lifetimes of the order of 5-10 Myr and a disc clearing time-scale significantly shorter than 1 Myr.

ALMA Observations of ρ-Oph 102: Grain Growth and Molecular Gas in the Disk around a Young Brown Dwarf *L. Ricci (CalTech), L. Testi (ESO), A. Natta, A. Scholz, I de Gregorio-Monsalvo (Santiago de Chile)*

A. Natta and A. Scholz as part of a consortium have presented Atacama Large Millimetre Array (ALMA) continuum and spectral line observations of the young brown dwarf ρ-Oph 102 at about 0.89 mm and 3.2 mm. They detected dust emission from the disk at these wavelengths and derived an upper limit on the radius of the dusty disk of around 40 au. The derived variation of the dust opacity with frequency in the millimetre (mm) provides evidence for the presence of mm-sized grains in the disk's outer regions. This result demonstrates that *mm-sized grains are found even in the low-density environments of brown dwarf disks and challenges our current understanding of dust evolution in disks.* The CO map at 345 GHz clearly reveals molecular gas emission at the location of the brown dwarf, indicating a gas-rich disk as typically found for disks surrounding young pre-main-sequence stars. They derived a disk mass of 0.3%-1% of the mass of the central brown dwarf, similar to the typical values found for disks around more massive young stars. The results were published in Astrophysical Journal and the European Southern Observatory

have made a press release of this discovery including a video http://www.eso.org/public/news/eso1248/.

Substellar Objects in Nearby Young Clusters (SONYC): The Planetary-mass Domain of NGC 1333 *A. Scholz, R. Jayawardhana (Toronto), K. Muzic (Toronto), V. Geers, Vincent, M. Tamura (Tokyo), I. Tanaka (Hilo, Hawaii)*

A. Scholz and V. Geers have continued their work as part of the SONYC (Substellar Objects in Nearby Young Clusters) survey, and have investigated the frequency of free-floating planetary-mass objects (planemos) in the young cluster NGC 1333. Building upon their extensive previous work, they have presented spectra for 12 of the faintest candidates from their deep multi-band imaging, plus seven random objects in the same fields, using MOIRCS on the Japanes Subaru Telescope. They confirm seven new sources as young very low mass objects (VLMOs), with T_{eff} of 2400-3100 K and mid-M to early-L spectral types. These objects add to the growing census of VLMOs in NGC 1333, now totalling 58. Three confirmed objects (one found in this study) have masses below 15 Jupiter masses, according to evolutionary models, thus are likely planemos. They estimate the total planemo population with 5 to 15 Jupiter masses M in NGC 1333 is around 8. The mass spectrum in this cluster is well approximated by $dN/dM \propto M^{-\alpha}$, with a single value of $\alpha = 0.6 \pm 0.1$ for masses less than 0.6 solar masses, consistent with other nearby star-forming regions, and requires $\alpha \leq 0.6$ in the planemo domain. These results in NGC 1333, as well as findings in several other clusters by this group and others, confirm that the star formation process extends into the planetary-mass domain, at least down to 6 Jupiter masses. However, given that planemos are 20-50 times less numerous than stars, their contribution to the object number and mass budget in young clusters is negligible. These findings *disagree strongly* with the recent claim from a micro-lensing study that free-floating planetary-mass objects are twice as common as stars. If the micro-lensing result is confirmed, those isolated Jupiter-mass objects must have a different origin from brown dwarfs and planemos observed in young clusters. Results have been published in Astrophysical Journal.

2.1.4 Outflows and Jets

Outflows from Brown Dwarfs. *E. Whelan, T. Ray, F. Comeron (ESO), F. Bacciotti (Florence), P. Kavanagh (Tübingen)*

Studies of the 24 Jupiter mass brown dwarf 2MASSJ12073347-3932540 using ESO's VLT have imaged a jet from a brown dwarf for the first time. In addition to the jet close to the source, knots were also seen to the south-west along the known outflow axis. The feature furthest from the source is bow-shaped, suggesting it is a supersonic shock, with the apex pointing away from 2MASSJ12073347-3932540. This is a first, as brown dwarf optical outflows have to date only been detected using the specialist technique of spectro-astrometry pioneered by the DIAS Star Formation Group. This result also demonstrates for the first time that BD outflows are highly collimated, episodic and a small-scale version of those seen in low mass stars. These results have been published in the Astrophysical Journal.

Very Large Array Observations of DG Tau's Radio Jet *C. Lynch (Iowa and DIAS), R. Mutel (Iowa), M. Güduel (Vienna), T.P. Ray, S. Skinner (Boulder), P.C. Schneider (Hamburg), K. Gayley (Iowa)*

The active young protostar DG Tau has an extended jet that has been well studied at radio, optical, and X-ray wavelengths. Lynch (Iowa/DIAS), T.P. Ray et al. have reported sensitive new Very Large Array (VLA) full polarization observations of the core and jet between 5 GHz and 8 GHz. Their high angular resolution observation at 8 GHz clearly shows an unpolarized inner jet with a size of 42 au (0.″35) extending along a position angle similar to the optical-X ray outer jet. Using their nearly coeval 2012 VLA observations, they find a spectral index $\alpha = +0.46 \pm 0.05$, which combined with the lack of polarization is consistent with bremsstrahlung (free-free) emission,

with no evidence for a non-thermal coronal component. By identifying the end of the radio jet as the optical depth unity surface, and calculating the resulting emission measure, they find that their radio results are in agreement with previous optical line studies of electron density and consequent mass-loss rate. They also detect a weak radio knot at 5 GHz located 7.″0 from the base of the jet, coincident with the inner radio knot detected in 2009 but at lower surface brightness. They interpret this as due to expansion of post-shock ionized gas in the three years between observations. The results will be published in Astrophysical Journal.

Jet Rotation Investigated in the Near-ultraviolet with the Hubble Space Telescope Imaging Spectrograph *D. Coffey, E. Rigliaco (Florence), F. Bacciotti (Florence), T.P. Ray, J. Eislöffel (Tautenburg)*

D. Coffey, T.P. Ray et al. have presented results of the second phase of their near-ultraviolet investigation into protostellar jet rotation using the Hubble Space Telescope Imaging Spectrograph. They have obtained long-slit spectra at the base of five T Tauri jets to determine if there is a difference in radial velocity between the jet borders which may be interpreted as a rotation signature. These observations are extremely challenging and push the limits of current instrumentation, but have the potential to provide long-awaited observational support for the magneto-centrifugal mechanism of jet launching in which jets remove angular momentum from protostellar systems. They successfully detected all five jet targets (from RW Aur, HN Tau, DP Tau, and CW Tau) in several near-ultraviolet emission lines, including the strong Mg II doublet. However, only RW Aur's bipolar jet presents a sufficiently high signal-to-noise ratio to allow for analysis. The approaching jet lobe shows a difference of 10 kms^{-1} in a direction which agrees with the disk rotation sense, but is opposite to previously published optical measurements for the receding jet. The near-ultraviolet difference is not found six months later, nor is it found in the fainter receding jet. Overall, in the case of RW Aur, differences are not consistent with a simple jet rotation interpretation. Indeed, given the renowned complexity and variability of this system, it now seems likely that any rotation signature is confused by other influences, with the inevitable conclusion that RW Aur is not suited to a jet rotation study. These results have been published in the Astrophysical Journal.

AMI radio continuum observations of young stellar objects with known outflows *R. Ainsworth (DIAS PhD student), A. Scaife, T.P. Ray and the AMI Consortium*

R. Ainsworth, A. Scaife, T.P. Ray and the Arcminute Micro-kelvin Imager (AMI) Consortium have presented 16 GHz (1.9 cm) deep radio continuum observations made with AMI) of a sample of low-mass young stars driving jets. We combine these new data with archival information from an extensive literature search to examine spectral energy distributions (SEDs) for each source and calculate both the radio and sub-mm spectral indices in two different scenarios: (1) fixing the dust temperature (T_d) according to evolutionary class; and (2) allowing T_d to vary. We use the results of this analysis to place constraints on the physical mechanisms responsible for the radio emission. From AMI data alone, as well as from model fitting to the full SED in both scenarios, we find that 80 per cent of the objects in this sample have spectral indices consistent with free-free emission. We find an average spectral index in both T_d scenarios, consistent with free-free emission. We examine correlations of the radio luminosity with bolometric luminosity, envelope mass and outflow force, and find that these data are consistent with the strong correlation with envelope mass seen in lower luminosity samples. We examine the errors associated with determining the radio luminosity and find that the dominant source of error is the uncertainty on the opacity index, β.

AMI-LA radio continuum observations of Spitzer c2d small clouds and cores: Serpens region *A. Scaife and the AMI Consortium*

A. Scaife and the AMI Consortium have presented deep radio continuum observations of

the cores identified as embedded young stellar objects in the Serpens molecular cloud by the Spitzer c2d programme at a wavelength of 1.8 cm with the Arcminute Microkelvin Imager Large Array (AMI-LA). These observations have a resolution of approximately 30.″0 and an average sensitivity of 19 μJy beam^{-1}. The targets are predominantly Class I sources, and they find the detection rate for Class I objects in this sample to be low (18%) compared to that of Class 0 objects (67%), consistent with previous works. For detected objects they have examined correlations of radio luminosity with bolometric luminosity and envelope mass and find that these data support correlations found by previous samples, but do not show any indication of the evolutionary divide hinted at by similar data from the Perseus molecular cloud when comparing radio luminosity with envelope mass. They conclude that envelope mass provides a better indicator for radio luminosity than bolometric luminosity, based on the distribution of deviations from the two correlations. Combining these new data with archival 3.6 cm flux densities they have also examined the spectral indices of these objects and find an average spectral index consistent *with the canonical value for a partially optically thick spherical or collimated stellar wind*. However, they caution that possible inter-epoch variability limits the usefulness of this value, and such variability is supported by their identification of a possible radio flare in Serpens SMM 1. These results have been published in Monthly Notices of the Royal Astronomical Society.

2.1.5 Comparing the Magnetic Topologies of of Main Sequence and Pre-Main Sequence Stars

Can We Predict the Global Magnetic Topology of a Pre-main-sequence Star from Its Position in the Hertzsprung-Russell Diagram? *S.G. Gregory (CalTech), S. G., J.F. Donati (Toulouse), J.A. Morin, G.A. Hussain (ESO), N.J. Mayne (Exeter), L.A. Hillenbrand (CalTech), M. Jardine (St. Andrews)*

Zeeman-Doppler imaging studies have shown that the magnetic fields of T Tauri stars can be significantly more complex than a simple dipole and can vary markedly between sources. J. Morin and his collaborators have collected and summarized the magnetic field topology information obtained to date and have presented Hertzsprung-Russell (H-R) diagrams for the stars in the sample. Intriguingly, the large-scale field topology of a given pre-main-sequence (PMS) star is strongly dependent upon the stellar internal structure, with the strength of the dipole component of its multipolar magnetic field decaying rapidly with the development of a radiative core. Using the observational data as a basis, this group have argued that the general characteristics of the global magnetic field of a PMS star can be determined from its position in the H-R diagram. Moving from hotter and more luminous to cooler and less luminous stars across the PMS of the H-R diagram, they present evidence for four distinct magnetic topology regimes. Stars with large radiative cores, empirically estimated to be those with a core mass in excess of around 40% of the stellar mass, host highly complex and dominantly non-axisymmetric magnetic fields, while those with smaller radiative cores host axisymmetric fields with field modes of higher order than the dipole dominant (typically, but not always, the octupole). Fully convective stars above 0.5 M_{sun} appear to host dominantly axisymmetric fields with strong (kilo-Gauss) dipole components. Based on similarities between the magnetic properties of PMS stars and main-sequence M-dwarfs with similar internal structures, they speculate that a bistable dynamo process operates for lower mass stars (less than 0.5 M_{sun} at an age of a few Myr) and that they will be found to host a variety of magnetic field topologies. If the magnetic topology trends across the H-R diagram are confirmed, they may provide a new method of constraining PMS stellar evolution models.

2.2 High-Energy Phenomena

2.2.1 Radiation Processes

Theory of magneto-bremsstrahlung in strong

magnetic fields revisited. *S. R. Kelner and F. A. Aharonian*

The character of radiation of relativistic charged particles in strong magnetic fields largely depends on the disposition of particle trajectories relative to the field lines. The motion of particles with trajectories close to the curved magnetic lines is usually referred to the so-called curvature radiation. The latter has been treated within the formalism of synchrotron radiation by replacing the particle Larmor radius with the curvature radius of the field lines. However, even at small pitch angles, the curvatures of the particle trajectory and the field line may differ significantly. Moreover, the trajectory curvature varies with time, i.e. the process has a stochastic character. Therefore for calculations of observable characteristics of radiation by an ensemble of particles, the radiation intensities should be averaged over time. In this paper, for determination of particle trajectories we use the Hamiltonian formalism, and show that that close to curved magnetic lines, for the given configuration of the magnetic field, the initial point and particle energy, always exist a smooth trajectory without fast oscillations of the curvature radius. This is the trajectory which is responsible for the curvature radiation. The result might have direct relation to the recent spectral measurements of gamma-radiation of pulsars. This work has been submitted to Phys Rev D [99].

Nuclear reactions in subrelativistic astrophysical plasmas *E. Kafexhiu, F. A. Aharonian, G. S. Vila, M. Barkov and R. A. Sunyaev*

The importance of nuclear reactions in low-density astrophysical plasmas with ion temperatures $T \geq 10^{10}$ K K has been recognized for almost thirty years ago (Aharonian and Sunyaev 1984). However, the lack of comprehensive data banks of relevant nuclear reactions and the limited computational power have not previously allowed detailed theoretical studies. Recent developments in these areas make it timely to conduct comprehensive studies on the nuclear properties of very hot plasmas formed around compact relativistic objects such as black holes and neutron stars. Such studies are of great interest in the context of scientific programs of future low-energy cosmic ?-ray spectrometry. In this work, using the publicly available code TALYS, we have built a large nuclear network relevant for temperatures exceeding 10^{10} K We have studied the evolution of the chemical composition and accompanying prompt gamma-ray emission of such high-temperature plasmas. We present the results on the abundances of light elements D, T, ^{3}He, ^{4}He, ^{6}Li, ^{7}Li, ^{9}Be, ^{10}B, ^{11}B, and briefly discuss their implications on the astrophysical abundances of these elements. In the subsequent paper we have studied also the gamma-ray emissivity due to the capture of neutrons by protons, p-n bremsstrahlung, and gamma-rays from decays of neutral pions produced at pp interactions in different regimes of accretion flows [47].

Analytical expressions for inverse Compton radiation close to the cutoff energy. *E. Lefa, S. R. Kelner, F. A. Aharonian*

The spectral shape of radiation due to inverse Compton scattering is analyzed in the Thomson and the Klein-Nishina regime for distributions of relativistic electrons with exponential cutoff. Simple analytical expressions for the gamma-ray spectra spectrum close to the maximum cutoff region are derived. Planckian (black-body) radiation and the synchrotron photons as target photon fields. for inverse Compton scattering have been analyzed. These approximations provide a direct link between the distribution of parent electrons and the upscattered gamma-ray spectrum in the cutoff region [50].

2.2.2 Ultrarelativistic electron-positron pulsar winds

F. A. Aharonian, D. Khangulyan, S. I. Bogovalov, D. Malyshev and M. Ribo

Pulsars are thought to eject electron-positron winds that energize the surrounding environment, with the formation of a pulsar wind nebula. The pulsar wind originates close to the

light cylinder, the surface at which the pulsar co-rotation velocity equals the speed of light, and carries away much of the rotational energy lost by the pulsar. Initially the wind is dominated by electromagnetic energy (Poynting flux) but later this is converted to the kinetic energy of bulk motion. It is unclear exactly where this takes place and to what speed the wind is accelerated. Although some preferred models imply a gradual acceleration over the entire distance from the magnetosphere to the point at which the wind terminates, a rapid acceleration close to the light cylinder cannot be excluded. Based on the recent observations of pulsed, very high-energy γ-ray emission from the Crab pulsar by the MAGIC and VERITAS collaborations, we have proposed that the latter can be best explained by the presence of a 'cold' ultrarelativistic wind dominated by kinetic energy. The conversion of the Poynting flux to kinetic energy should take place abruptly in the narrow cylindrical zone of radius between 20 and 50 light-cylinder radii centred on the axis of rotation of the pulsar, and should accelerate the wind to a Lorentz factor of $(0.5-1.0)\times 10^6$.

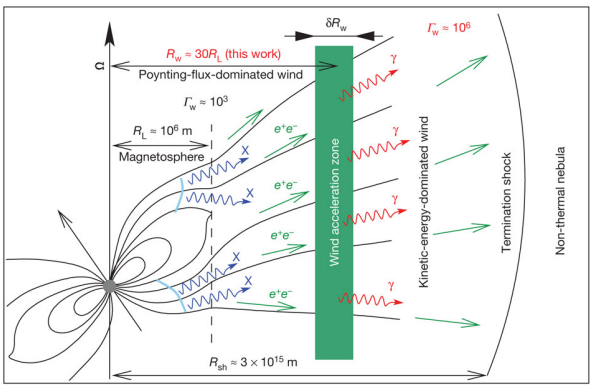

Figure 1:

The second evidence of a signal from the unshocked pulsar wind we found from the binary pulsar PSR B1259-63/LS2883. Namely, we claimed that the bright gamma-ray flare of this object detected by the *Fermi* telescope is due to the inverse Compton scattering of the unshocked electron-positron pulsar wind with a Lorentz factor $\Gamma_0 \approx 10^4$. The combination of two effects, both linked to the circumstellar disk (CD), is a key element in the proposed model. The first effect is related to the impact of the surrounding

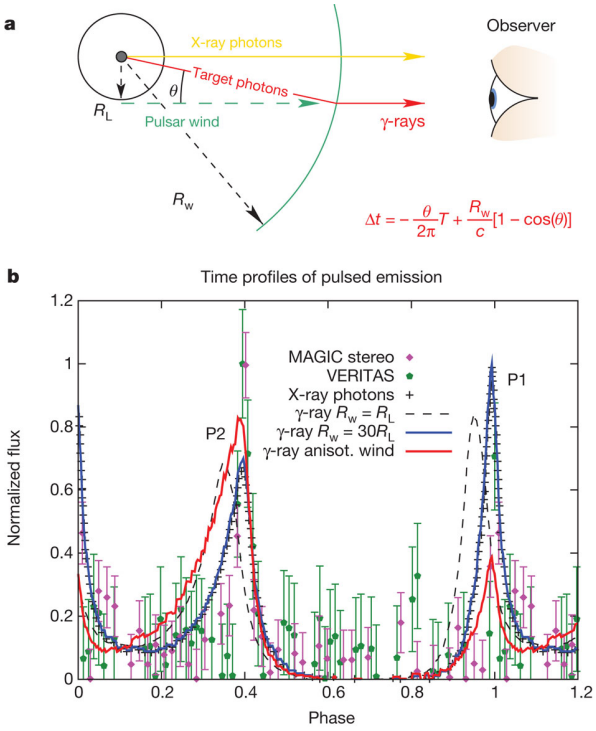

Figure 2:

medium on the termination of the pulsar wind. Inside the disk, the 'early' termination of the wind results in suppression of its gamma-ray luminosity. When the pulsar escapes the disk, the conditions for termination of the wind undergo significant changes. This could lead to a dramatic increase of the pulsar wind zone, and thus to the proportional increase of the gamma-ray flux. On the other hand, if the parts of the CD disturbed by the pulsar can supply infrared photons of density high enough for efficient Comptonization of the wind, almost the entire kinetic energy of the pulsar wind would be converted to radiation, thus the gamma-ray luminosity of the wind could approach the level of the pulsar's spin-down luminosity as reported by the Fermi Collaboration.

The energy spectrum of IC radiation of the unshocked pulsar wind strongly depends on the spectrum of the target photon field. If it dominates by a hot thermal radiation emitted, for example, from the surface of the neutron star, we should expect a sharp spectral feature formed in the deep Klein-Nishina regime with an energy $E = m_e c^2 \Gamma_0$. This scenario of formation of a line-

like spectral feature above 100 GeV, has been invoked by us as an alternative source for the narrow gamma-ray line at 130 GeV reported recently from the direction of the Galactic Center. This explanation is alternative to the interpretation that refers the reported 130 GeV line to the annihilation of Dark Matter. In this paper we argue that cold ultrarelativistic pulsar winds can be alternative sources of very narrow gamma-ray lines. The confirmation of this exciting gamma-ray line emission by future independent measurements would be crucial for resolving the spatial structure of the reported hotspots, and thus for distinguishing between the dark matter and pulsar origins of this unusual spectral feature.

This work was published in Nature [6] as well as in [48, 7]

2.2.3 MHD simulations and implications for radiation of relativistic outflows

S. Bogovalov, D. Khangulyan, A. Koldoba, G. Ustyugova and F. A. Aharonian The high energy gamma-ray emission of relativistic outflows like pulsar winds or AGN jets has been one of the central research topics of our group. While in our previous studies we put an emphasis on the modeling of radiation processes, recently we started to pay more attention to the (magneto)hydrodynamics of the relativistic outflows interacting with surrounding medium. In particular,

(ii) Interaction of the pulsar and stellar winds in the binary system PSR B1259-63/SS2883. We studied the impact of the strength of magnetic field and the wind anisotropy on the character of interaction of the relativistic pulsar wind with the non-relativistic stella wind. We showed, in particular, that although both effects change the shape of the region occupied by the terminated pulsar wind, their impact appears to be small. In particular, for the magnetization of the pulsar wind below 0.1, the magnetic field pressure remains well below the plasma pressure in the post-shock region. This is opposite to the case of the pulsar wind nebulae where the magnetic field becomes dynamically important independent of the level of the wind magnetization [19].

(ii) Simulations of stellar/pulsar-wind interaction along one full orbit.

V. Bosch-Ramon, M. Barkov, D. Khangulyan, M. Perucho The winds from a non-accreting pulsar and a massive star in a binary system collide forming a bow-shaped shock structure. The Coriolis force induced by orbital motion deflects the shocked flows, strongly affecting their dynamics. Relativistic hydrodynamical simulations in two dimensions, performed with the code PLUTO and invoking the adaptive mesh refinement technique, have been used to model the interacting stellar and pulsar winds on scales 80 times the distance between the stars. In addition to the shock formed towards the star, the shocked and unshocked components of the pulsar wind flowing away from the star terminate by means of additional strong shocks produced by the orbital motion. Strong instabilities lead to the development of turbulence and an effective two-wind mixing in both the leading and trailing sides of the interaction structure, which starts to merge with itself after one orbit. Simulations show that shocks, instabilities, and mass-loading yield efficient mass, momentum, and energy exchanges between the pulsar and the stellar winds. This renders a rapid increase in the entropy of the shocked structure. Several sites of particle acceleration and low- and high-energy emission have been identified. Doppler boosting might have significant effect on radiation [22].

2.2.4 Clouds and red giants interacting with AGN jets.

Extragalactic jets are formed by supermassive black-holes located in the centers of galaxies. Large amounts of gas clouds and stars clustered in the galaxy nucleus interact with the jet with important impact on the dynamics of the jet and its mass-loading. These interactions have been studied in the innermost regions of an extragalactic jet using relativistic hydrodynamical simulations with axial symmetry carried out for homogeneous and inhomogeneous clumps inside the relativistic jet. These clumps may repre-

sent a medium inhomogeneity or a disrupted atmosphere of a red giant star. Once inside the jet, the clump expands and gets disrupted after few dynamical timescales. In the inhomogeneous case, a solid core can smoothen the process with the clump mass-loss dominated by a dense and narrow tail along the direction of the jet. In either case, matter of the clump is expected to be eventually incorporated to the jet. Particles, electrons and positrons, can be accelerated in the interaction region, and produce variable gamma-rays at interactions with the ambient plasma, magnetic and radiation fields. Very fast flare-like gamma-ray events, are expected due to these interactions. We demonstrated this interesting feature of the jet-star interaction scenario, and propose viable models for explanation of the rapid TeV variability of the blazar PKS 2155-304 on minute scales, as well as the gamma-ray lightcurve of the nucleus of the nearby radiogalaxy M 87 [21, 17, 16]

2.2.5 Propagation of protons and gamma-rays through intergalactic radiation and magnetic fields

A. Prosekin, W. Essey, A. Kusenko and F.A. Aharonian

Blazars are expected to produce both gamma rays and cosmic rays. Therefore, observed high-energy gamma rays from distant blazars may contain a significant contribution from secondary gamma rays produced along the line of sight by the interactions of cosmic-ray protons with background photons through the Bethe-Heitel pair production and photomeson processes. The electrons and gamma-rays produced in these interactions initiate electromagnetic cascades through the photon-photon pair production and the inverse Compton scattering. The cascade photons contribute to signals of point sources only if the intergalactic magnetic fields are very small, less than 10-15 G, and their detection can be used to set upper bounds on magnetic fields along the line of sight. Secondary gamma rays have distinct spectral and temporal features. We explored the temporal properties of such signals using a semi-analytical formalism and detailed numerical simulations, which account for all the relevant processes, including magnetic deflections. In the case of very small intergalactic magnetic field, the photon-electron cascades can contribute significantly to the gamma-ray emission of distant blazars. At very high energies, the gamma-ray horizon of the universe is limited to redshifts $z \ll 1$, and, therefore, any observation of TeV radiation from a source located beyond z=1 would call for a revision of the standard paradigm. While robust observational evidence for TeV sources at redshifts $z > 1$ is lacking at present, the growing number of TeV blazars with redshifts as large as $z \approx 0.5$ suggests the possibility that the standard blazar models may have to be reconsidered. We show that TeV gamma rays can be observed even from a source at $z > 1$, if the observed gamma rays are secondary photons produced in interactions of high-energy protons originating from the blazar jet and propagating over cosmological distances almost rectilinearly. This mechanism was initially proposed as a possible explanation for the TeV gamma rays observed from blazars with redshifts $z \approx 0.2$, for which some other explanations were possible. For TeV gamma-ray radiation detected from a blazar with $z > 1$, this model would provide the only viable interpretation consistent with conventional physics. It would also have far-reaching astronomical and cosmological ramifications. In particular, this interpretation would imply very weak extragalactic magnetic fields along the line of sight (in the range $0.01\,\mathrm{fG} < B < 1\,\mathrm{fG}$) and very effective acceleration of $E > 0.1$ EeV protons in the jets of active galactic nuclei. [60, 94]

2.2.6 High Energy Processes in the Galactic Center

D. Jones, R. Crocker, W. Reich, J. Ott and F. A. Aharonian

Over the last several years, the central region of our Galaxy has been in the focus of interest of our group in general, and in the context of nonthermal processes, in particular. These processes proceed on different scales, from the compact regions near the central black hole Sag

A* to the 200 pc radius dense molecular zone, and giant gamma-ray structures, the so-called Fermi Bubbles - two enormous gamma-ray structures symmetrically extending to approximately 10 kpc above the Galactic plane. Recently we found a correspondence between giant, polarized microwave structures emerging north from the Galactic plane near the Galactic center and a number of GeV gamma-ray features, including the eastern edge of the recently discovered northern Fermi Bubble. The polarized microwave features also correspond to structures seen in the all-sky 408 MHz total intensity data, including the Galactic center Spur. The magnetic field structure revealed by the Wilkinson Microwave Anisotropy Probe polarization data at 23 GHz suggests that neither the emission coincident with the Bubble edge nor the Galactic center Spur are likely to be features of the local interstellar medium. On the basis of the observed morphological correspondences, similar inferred spectra, and the similar energetics of all sources, we proposed a direct connection between the Galactic center Spur and the northern Fermi Bubble. [46]

2.2.7 Light curves of soft X-ray transients in M31

N. Nooraee

Disc irradiation is thought to be capable of explaining the global behaviour of the light curves of soft X-ray transients (SXTs). Depending on the strength of the central X-ray emission in irradiating the disc, the light curve may exhibit an exponential or a linear decay. The model predicts that in brighter transients a transition from exponential decline to a linear one may be detectable. In this study, having excluded supersoft sources and hard X-ray transients, a sample of bright SXTs in M31 ($L_{\rm peak} > 10^{38}\,{\rm erg\,s^{-1}}$) has been studied. The expected change in the shape of the decay function is only observed in two of the light curves from the six light curves in the sample. Also, a systematic correlation between the shape of the light curve and the X-ray luminosity has not been seen.

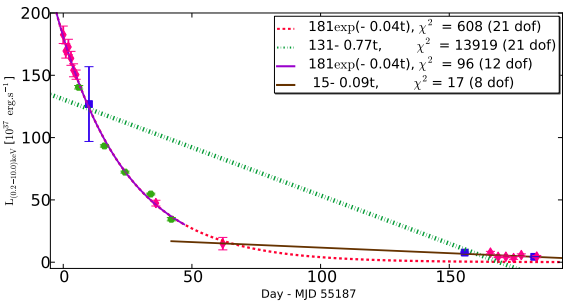

Figure 3: The X-ray light curve of CXOM31 J004253.1+411422 during its outburst based on data taken with three telescopes (Chandra/ACIS, the green hexagonal is XMM/EPIC-PN and the red diamond is Swift/XRT). Various combinations of exponential and linear fits to the data are also shown.

2.2.8 Superorbital modulation of X-ray emission from gamma-ray binary LSI +61 303

M. Chernyakova, A. Neronov, S. Molkov, A. Lutovinov, D. Malyshev and G. Pooley

We report the discovery of a systematic constant time lag between the X-ray and radio flares of the gamma-ray binary LSI +61 303, persistent over a long, multi-year timescale. Using the data from the monitoring of the system by RXTE we show that the orbital phase of X-ray flares from the source varies from ϕ_X 0.35 to ϕ_X 0.75 on the superorbital 4.6 yr timescale. Simultaneous radio observations show that periodic radio flares always lag the X-ray flare by $\delta\phi_{X-R}$ 0.2. We propose that the constant phase lag corresponds to the time of flight of the high-energy particle-filled plasma blobs from inside the binary to the radio emission region at the distance of 10 times the binary separation distance. We put forward a hypothesis that the X-ray bursts correspond to the moments of formation of plasma blobs inside the binary system.

2.2.9 Search for variable gamma-ray emission from the Galactic plane in the Fermi data

M. Chernyakova, A. Neronov, D. Malyshev, A. Lu-

tovinov and G. Pooley

High-energy gamma-ray emission from the Galactic plane above 100 MeV is composed of three main contributions: diffuse emission from cosmic ray interactions in the interstellar medium, emission from extended sources, such as supernova remnants and pulsar wind nebulae, and emission from isolated compact source populations. The diffuse emission and emission from the extended sources provide the dominant contribution to the flux almost everywhere in the inner Galaxy, preventing the detection of isolated compact sources. In spite of this difficulty, compact sources in the Galactic plane can be singled out based on the variability properties of their gamm-ray emission. Our aim is to find sources in the Fermi data that show long-term variability. We performed a systematic study of the emission variability from the Galactic plane, by constructing the variability maps. We found that emission from several directions along the Galactic plane is significantly variable on a time scale of months. These directions include, in addition to known variable Galactic sources and background blazars, the Galactic ridge region at positive Galactic longitudes and several regions containing young pulsars. We argue that variability on the time scale of months may be common to pulsars, originating from the inner parts of pulsar wind nebulae, similarly to what is observed in the Crab pulsar.

2.3 General Theory

2.3.1 Magnetic field amplification.

L. O'C. Drury and T. P. Downes

This is a current 'hot topic' in particle acceleration theory because it promises to resolve some of the major difficulties associated with the limitations on the maximum attainable energy. Most discussions have focused on a mechanism proposed by A Bell which is driven by the current of the accelerated particles[69]. There is an alternative mechanism driven simply by the pressure of the accelerated particles which offers some significant advantages, but which has not been explored in as much depth. In collaboration with Turlough Downes a simple toy computational model was developed and first numerical simulations carried out to confirm the potential of this process. [34]

2.3.2 Acceleration by Magnetic Reconnection.

L. O'C. Drury and V. Bosch-Ramon

There has been speculation that magnetic reconnection can drive a Fermi acceleration process analogues to diffusive shock acceleration. Some errors in the previous literature were pointed out and the limitations of this process discussed. [20, 32]

2.4 Invited talks and other conference activities

Felix Aharonian gave an invited talk on "X-ray emission of secondary electrons as a tool for probing hadronic sources" at the workshop 'Exploring nonthermal Universe with ASTRO-H', Hakone, Japan, 17-19 May , 2012;

gave an invited talk on 'High Energy Gamma Sources at the conference '100 years of cosmic rays', Bad Saarow, Germany, 5-8 Aug, 2012;

gave the summary talk on 'The origin of Galactic cosmic rays' at the workshop 'Searching for the sources of galactic cosmic rays', Paris, France, 12-14 Dec, 2012.

was the main organizer (Chair of SOC) of the 5th International Symposium on "High Energy Gamma-Ray Astronomy", 9-13 July, Heidelberg, Germany. This is the 5th of the largest regular (once per 4 years) meeting on gamma ray astronomy which he initiated in the mid 1990s;

participated, as a member of SOC, in the organization of the following scientific meetings: Positrons in Astrophysics (International Workshop; March 20-23, 2012,

Mörren, Bernese, Oberland, Switzerland; Near Infrared Background and the Epoch of Reionization, May 14-15, Austin, Texas, USA; Science with the New Generation of High Energy Gamma-ray Experiments Lecce, Italy, June 20-22, 2012; 100 years of Cosmic Rays - Anniversary of their Discovery by Victor Hess, Bad Saarow, Germany, 5-8 Aug, 2012; CTA-LINK meeting, Buenos-Aires, Argentine, Nov 19-21; 26th Texas Symposium on Relativistic Astrophysics Sao Paulo, Brazil, December 15-20, 2012.

Luke Drury gave the opening invited talk at a conference in Poellau, Austria, to mark the centenary of Victor Hess's discovery of cosmic rays;

participated in the ESOF2012 event and introduced the key-note event commemorating Schroedinger's 'What is Life?' lectures as well as chairing a session on Black Holes;

gave a talk on Magnetic Field Amplification in SNR shocks' at the festconference to honour Felix Aharonian's 60th birthday held in Barcelona.

Valenti Bosch-Ramon gave invited talks on:

'High-energy process in gamma-ray binaries', 5th International Symposium on High-Energy Gamma-Ray Astronomy, July Heidelberg, Germany, 9-14 July, 2012;

'Gamma-ray emission from high-mass X-ray binaries', COSPAR 2012, Misore, India, 14-22 July, 2012;

'Gamma-Ray Binaries, Exploring the Non-thermal Universe with Gamma Rays', Barcelona, Spain, 6-9 November, 2012.

3 Contributions to Third-level Education

Felix Aharonian gave two lectures on 'Active galactic nuclei from radio to gamma-rays' as a part of the course of 'Astrophysical and Space Plasmas' at the International School of Space Science, L'Aquila (Italy), September 3-7, 2012;

gave three lectures on 'Gamma Rays from Active Galactic Nuclei' (1. Introduction, 2. Production sites, acceleration/radiation mechanisms, 3. Cosmological implications) at the at the School of the IRAP Ph.D. Erasmus Mundus Joint Doctorate Program (University of Nice), 3-21 September, 2012.

supervised 2 PhD students in DIAS, 4 PhD students in MPIK, Heidelberg, and 1 PhD student in the La Sapienza University of Rome (3 received their PhD in 2012)

Tom Ray gave a course of 9 lectures on introductory Astronomy and Astrophysics to Junior Freshman students and 14 lectures on Galactic Dynamics to Junior Sophister students in TCD Physics. He also gave lectures as part of the course of Astrophysical and Space Plasmas' at the International School of Space Science, L'Aquila (Italy), September 3-7, 2012; supervised 4 DIAS PhD students Paul Dawson, Rachael Ainsworth and Grainne Costigan and Donna Lee Rodgers (from Trinity College Dublin) from 1st December. Grainne Costigan (the Lindsay Scholar jointly with Armagh Observatory) is currently on a stipend funded by the European Southern Observatory at ESO Headquarters in Garching, Germany.

Luke Drury served as a member of the Search Committee for the next President of UCD which met on several occasion during the year.

Alex Scholz co-supervised DIAS the PhD students, Paul Dawson and Grainne Costigan.

Vincent Geers co-supervised Donna Rodgers Lee.

4 Contributions to research infrastructure and public service

4.1 Space Missions: JWST and EChO

The Mid-Infrared Instrument (MIRI) on the James Webb Space Telescope. In early 2012 the MIRI Flight Model (FM) completed testing at the Rutherford Appleton Laboratories in Oxford before being shipped to NASA Goddard following acceptance by the NASA/ESA Delivery Review Board (DRB). At Goddard, it is currently (November 2012) being integrated into the Instrument Science Module (ISM) with the Fine Guidance Sensor (FGS) and Near-InfraRed Imaging Slitless Spectrograph (NIRISS) from Canada. DIAS personnel will attend a training session in NASA Goddard in December with the intention of supporting the first combined test of MIRI, the FGS and NIRISS in the Goodard cryo-chamber around March 2013. Two new people have been recruited to the MIRI project from December 2012 with funding for the next 3 years through ESA's PRODEX Office. They are Ruymán Azzollini (formerly INTA, Madrid) and Vincent Geers (formerly ETH, Zurich). Both will play a key role in the development of data analysis software for MIRI in collaboration with the Space Telescope Science Institute in Baltimore.

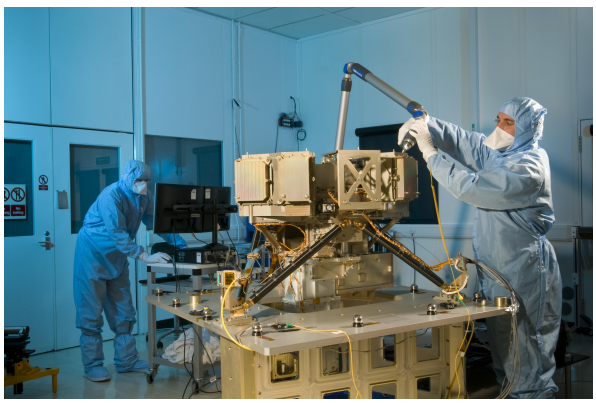

Figure 4: MIRI being aligned at the Rutherford Appleton Laboratory prior to its shipment to NASA Goddard. The emphasis at DIAS has now shifted to development of MIRI data analysis software and improved pipeline calibration.

Exoplanet Characterisation Observatory (EChO). DIAS has become a partner (T.P. Ray is a Co-PI) in the proposed Exoplanet Characterisation Observatory (EChO). This space observatory aims to analyse the atmospheres of planets around neighbouring stars and is currently being considered by ESA as an M-Class mission. EChO uses the principle that during a primary transit, when a planet crosses in front of its host star, the star's light passes through the edge of the planet's atmosphere, effectively providing an atmospheric transmission spectrum. In contrast the dip in its flux at infrared wavelengths reveals the emission, and at optical wavelengths, the reflection, spectrum of the planet during a secondary eclipse when the planet goes behind its star. Light-curves can thus be built up that map the temperature and composition of an exoplanet. It is envisaged, assuming the mission is accepted by ESA, that DIAS will provide beam splitters for the on board spectrometer and that it will also be involved, with Rutherford Appleton Laboratory, in establishing the infra-red detector characteristics and developing data analysis software for the detectors.

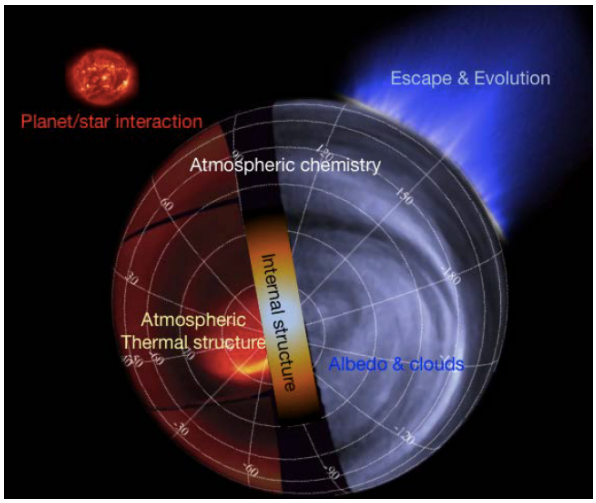

Figure 5: The Exoplanet Characterisation Observatory (EChO) is a medium sized mission currently being proposed to ESA. This figure illustrates its main objectives. T.P. Ray has joined the Consortium as Co-Principal Investigator. EChO will study the atmospheres of exoplanets using planetary transits.

4.2 HESS, Fermi, ASTRO-H, KM3NeT, CTA

The high-energy and astroparticle physics group in DIAS remains an active member of the HESS collaboration and participates in the production of high-impact papers of HESS. We also are involved in the data analysis, interpretation and publication of results based on the publicly available data banks of the the Fermi Large Array Telescope (LAT). We actively participate in the process of writing papers on the potential of the future gamma-ray (CTA) and neutrino (KM3NeT) telescopes. Finally, we play an important role in the preparation of scientific program of the future X-ray mission ASTRO-H.

4.3 e-Inis

The Institute-led e-INIS project to develop the shared national e-Infrastructure achieved further significant impact during 2012 before working toward project closure at year-end.

The National HPC Service operated by project partners ICHEC (Irish Centre for High End Computing) continues to fulfill a key enabling role across a broad and growing range of research disciplines in Ireland. In excess of 70 peer-reviewed publications were supported by access to ICHEC resources over the 2012 calendar year. Demand for the national HPC service continues to grow and this is no doubt partly attributable to the excellent user support and the development of the computational science community through ongoing training programmes. User support, training and improved access are key e-INIS funded activities within ICHEC.

In the early part of the year, the e-INIS project co-ordinator Keith Rochford was seconded to ICHEC to assist with the administration of the centre during a difficult period of transition. During that secondment, Keith played a significant role in the preparation of several funding proposals to sustain and enhance the Centre including a successful SFI recurrent award (M€1.4) and the Centre's response to the SFI equipment call to renew the compute infrastructure on which the national HPC service is operated (M€4.6).

It is regrettable that Grid-Ireland, Ireland's National Grid Initiative and partner in the EU EGEE and EGI projects, was forced to wind down operations in the latter part of the year and the Grid operation centre hosted at TCD closed officially on December 31st. As an active participant in the e-INIS collaborations, Grid-Ireland made significant contributions to the international Grid computing effort although a lack of domestic user-demand (and hence recognition of value) has led to a shortage of the recurrent funding required to maintain operations.

The users of the grid-connected computational resources are expected to migrate to the HPC systems operated by ICHEC and TCHPC and the Institute has worked with Grid-Ireland and HEAnet to migrate the essential Certificate Authority (CA) service to HEAnet, ensuring continuity of this service. The CA service is required for access to many of the shared e-infrastructure resources across Europe.

Ireland's capacity for data-driven and data-intensive research was further bolstered with the addition of a new node on the federated national data store. Following an full EU public procurement exercise led by the Institute, an additional 900 terabytes of storage capacity with associated storage interconnect and front-end service platform was installed in the UCD hosting centre adjacent to the home of the e-INIS HPC cluster, Stokes. This brings the total available storage capacity brought online during the project to 2039 TB. Recognising that the useful life of this infrastructure extends considerably beyond the life of the project, the e-INIS project executive agreed to the Institute's recommendation that the management of this latest resource be taken on by ICHEC and that it be operated in conjunction with the HPC service. We expect ICHEC to leverage the synergy achieved through the integration of data and HPC to foster further expertise in the areas of analytics and data-intensive computing.

The Institute has engaged with HEAnet and ICHEC to rationalise the design of the e-INIS high-performance network infrastructure deployed in 2008 to integrate the distributed shared

ICT resources across Ireland. The re-design aims to meet current demand from the research community while reducing the overall cost of network operations. In the absence of a budget for continued operation, a number of the links on the network have been decommissioned or downgraded. It is anticipated that growing demand from the user community will demand improved performance and justify further investment in the medium-term.

The e-INIS project has significantly advanced both the capability and capacity of the ICT infrastructure available to Irish researchers and their international collaborators. In light of the diminished available funding we have undertaken the rationalisation and consolidation of activities as required to sustain essential levels of service and to support the continued advancement and competitiveness of Irish research.

4.3.1 Individual Contributions

Felix Aharonian as the newly-elected vice president of the Division of the International Astronomical Union (IAU) 'High Energy Phenomena and Fundamental Physics' participated in the process of restructuring of the Divisions of IAU, creation of new Commissions and Working Groups, etc; as the ESA representative in the ASTRO-H project, during his 6weeks visit to ISAS/JAXA (Tokyo, Japan) in April-May 2012, has been leading work on the preparation of the scientific program of the ASTRO-H satellite related to the non-thermal aspects of observations with this X-ray mission; participated in the preparation of the document 'Pathway to the Square Kilometer Array (the German White paper)' ;served as an editor of the International Journal of Modern Physics.

Luke Drury served as a panel member evaluating ERC starter and consolidator proposals in January and March. In each case this involved several days in Brussels as well as considerable prior preparation; as President of the RIA, co-ordinated the production of a working paper on third-level governance at the request of the Minister for Education; helped tp organise the Dialogue Forum on Research Funding. http://www.ria.ie/ria/media/riamedialibrary/documents/about/policy%20documents/research-dialogue-report-16-novx.pdf; served as a member of advisory oversight board of the Irish Centre for High-End Computing (ICHEC).

Tom Ray became a member of the European Southern Observatory's Observing Programme Committee (OPC) and a Panel Chair (Interstellar Medium, Star Formation and Solar System) for the European Southern Observatory; he served in Brussels on the Marie Curie Fellowship Physics Panel; served on the Council of the Royal Irish Academy; served as Postgraduate Studies Advisor to the School, served on the Science and Technology Facilities Council (STFC) e-MERLIN Steering Committee; served on the RIA Astronomy and Space Science Committee; served on ESA's MIRI Steering Committee, served as a member of the irish Fulbright Panel.

Aleks Scholz became an advisor to the European Southern Observatory's OPC.

Malcolm Walmsley continued to serve as an editor of Astronomy and Astrophysics.

Antonella Natta served as a panel member evaluating ERC starter and consolidator proposals in January and March.

5 Public Outreach

The main, though not exclusive, focus of outreach work in the section is through Dunsink Observatory. In addition to the standard open-night events (see below) of which there were 12, including 4 family orientated evenings, and other special interest groups visiting there were three noteworthy developments. Firstly, we were able to run for the first time an event in cooperation

with an industrial partner; DELL corporation organized a successful national HPC event in Dunsink and were delighted with the facilities available. Secondly, the Department of Education ran an in-house training event for primary teachers on astronomy in the curriculum using Dunsink. Thirdly, both a group from TCD and one from the NUI have made use of Dunsink as a location for an away-day period of strategic review. It is clear that the facility is addressing a real need and we may expect increased demand as word spreads.

Detailed List of Events Family Evening Events: 7th March, 23rd March, 10th April, and 25th October.

Normal Public Open Nights: 18th January, 1st February, 22nd February, 21st March, 28th March, 3rd October, 17th October 2012, and 7th November 2012.Special Day/Evening Events 2012: 8th February, UCD Group; 16th February, Failte Ireland; 6th March, DCU; 14th March, Marino College Group; 14th March, ESB; 28th March, Hamilton Festival; 26th March, SCP Board Meeting; 3rd April, Fingal County Council Meeting with DIAS; 20th April, Meeting with Fingal Planners; 21st June, TCD School of Physics Away Day; 23rd June, Solarfest; 2nd – 6th July, Teacher Training Week; 6th July, Italian Student Group; 20th July, Teagasc; 6th August , Zara Gifted Children Day; 22nd September, West of Ireland Astronomy Society; 21st September, Dublin City of Culture Evening; 16th October, Hamilton Walk; 18th October, Dell Day; 19th October, Poterstown Beavers Group; 24th October, Dunboyne Club; 25th October, Fingal Historial Society; 28th October, Russian Embassy Culture Day; 7th October, TCD Transition Year Group; 12th – 16th November, Science Week; 21st November, Trinity Biomedical Science Institute.

Dunsink Observatory was very busy during Science Week which ran from the 12th to the 16th November. There were day sessions for national schools from Wicklow, Kildare, Meath and Dublin and, in addition, evening sessions for secondary schools from Dublin City and its surroundings. In total 10 groups visited the observatory.The speakers, all who were from DIAS or with strong DIAS connections, who volunteered to gave talks in Dunsink Observatory during 2012, either for special events or the normal public open nights, included: Luke Drury, Tom Ray, Aleks Scholz, Andrew Taylor, Rachel Ainsworth, Iurii Babyk, Grainne Costigan, Paul Dawson, Turlough Downes, Emma Whelan, Nakisa Nooraee, Gareth Murphy, Lisa Fallon, Sean Delaney, Paul Dempsey, Masha Chernyakova, Valenti Bosch-Ramon, and Keith Rochford. In addition Peter Gallagher, Brian Espey and David Malone from TCD gave talks as did Brendan Boulter from Dell (Science Week) and Fergal Mullaly from NASA on the Kepler Mission on 27th June and 26th December.

Detailed organisation for many of the above events was carried out by Hilary O'Donnell. She was assisted by DIAS technical staff members, Eileen Flood and Anne Grace, on numerous occasions. Moreover, as in previous years volunteers from the Irish Astronomical Society and the Irish Astronomical Association helped out. In particular Terry Moseley, Michael O'Connell, John Flannery, Deirdre Kelleghan, Val Dunne and Robin Moore enthusiastically talked to the public about the beauty of the Night Sky.

Figure 6: Prof Clive Ruggles, Minister Joan Burton and Luke Drury at the launch of the Irish Astronomy Trail in Dunsink Observatory

In addition to this use as a meeting venue, the more conventional outreach aspect can only expect to grow after the launch of the Irish Astronomy trail and the great success of opening for the first time as part of Culture night.

6 Detailed Bibliography of Publications

Note that where possible hyperlinks have been provided to the journal article and preprint version.

6.1 Peer-reviewed Publications in 2012

[1] A. Abramowski et al. "Discovery of extended VHE γ-ray emission from the vicinity of the young massive stellar cluster Westerlund 1". In: A&A 537, A114 (Jan. 2012), A114. DOI: 10.1051/0004-6361/201117928. arXiv:1111.2043 [astro-ph.HE].

[2] A. Abramowski et al. "Probing the extent of the non-thermal emission from the Vela X region at TeV energies with H.E.S.S." In: A&A 548, A38 (Dec. 2012), A38. DOI: 10.1051/0004-6361/201219919. arXiv:1210.1359 [astro-ph.HE].

[3] A. Abramowski et al. "Search for Dark Matter Annihilation Signals from the Fornax Galaxy Cluster with H.E.S.S." In: ApJ 750, 123 (May 2012), p. 123. DOI: 10.1088/0004-637X/750/2/123. arXiv:1202.5494 [astro-ph.HE].

[4] A. Abramowski et al. "Spectral Analysis and Interpretation of the γ-Ray Emission from the Starburst Galaxy NGC 253". In: ApJ 757, 158 (Oct. 2012), p. 158. DOI: 10.1088/0004-637X/757/2/158. arXiv:1205.5485 [astro-ph.HE].

[5] A. Abramowski et al. "The 2010 Very High Energy γ-Ray Flare and 10 Years of Multi-wavelength Observations of M 87". In: ApJ 746, 151 (Feb. 2012), p. 151. DOI: 10.1088/0004-637X/746/2/151. arXiv:1111.5341 [astro-ph.CO].

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[8] F. Aharonian et al. "Cosmic Rays in Galactic and Extragalactic Magnetic Fields". In: Space Sci. Rev. 166 (May 2012), pp. 97–132. DOI: 10.1007/s11214-011-9770-3. arXiv:1105.0131 [astro-ph.HE].

[9] AMI Consortium et al. "A blind detection of a large, complex, Sunyaev-Zel'dovich structure". In: MNRAS 423 (June 2012), pp. 1463–1473. DOI: 10.1111/j.1365-2966.2012.20970.x. arXiv:1012.4441 [astro-ph.CO].

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[12] AMI Consortium et al. "Arcminute Microkelvin Imager observations of unmatched Planck ERCSC LFI sources at 15.75 GHz". In: MNRAS 421 (Mar. 2012), pp. L6–L10. DOI: 10.1111/j.1745-3933.2011.01195.x. arXiv:1110.1454 [astro-ph.GA].

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6.2 Publications in 2012 (not subject to peer-review)

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